ONR Graduate Traineeship Award in Ocean Acoustics for Ioannis Bertsatos

PI: Prof. Nicholas C. Makris
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room 5-212
Cambridge, MA 02139
phone: (617) 258-6104   fax: (617) 253-2350   email: makris@mit.edu

Co-PI: Ioannis Bertsatos
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room 5-435
Cambridge, MA 02139
phone: (617) 253-1032   fax: (617) 253-2350   email: ibertsat@mit.edu

LONG-TERM GOALS

1. Passive Source Localization in a Fluctuating Ocean Waveguide

The long-term goal of this research is to determine necessary conditions on controllable experimental quantities, such as sample size or signal-to-noise ratio (SNR), so that source localization estimates in a fluctuating ocean waveguide can attain design error thresholds. Using asymptotic expansions of the bias and covariance of maximum likelihood estimates (MLEs) in inverse orders of sample size or SNR,[1] we aim to derive an analytical expression for the second-order covariance of MLEs obtained from general complex Gaussian data vectors. This expression can then be used to specify necessary conditions for accurate estimation in many practical problems where both the mean and variance of the measurement are functions of the estimation parameters. Currently such conditions can only be determined in cases where either the mean or the variance of the measurement is parameter dependent, but not both.[2] Our ultimate goal is to quantify the effects of internal waves on the biases and variances of source localization estimates, as well as on the sample sizes and SNRs required to obtain accurate estimates.

2. Velocity Estimation of Underwater Target Swarms

The long-term goal of this research is to develop a method for instantaneously estimating the means and standard deviations of the velocity and position of groups of self-propelled underwater scatterers observed by a long-range remote sensing system. We aim to obtain these estimates based on an analytical expression for the magnitude squared of the range-velocity ambiguity function of the acoustic field scattered from such target groups. This expression can then be used to estimate the first and second moments of the targets' velocity and position. Currently no technique exists to simultaneously estimate the second-order velocity and position statistics of underwater target groups. Our ultimate goal is to utilize such estimates to instantaneously distinguish and classify underwater targets.

Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 2009**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **ONR Graduate Traineeship Award In Ocean Acoustics For Ioannis Bertsatos**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,77 Massachusetts Avenue, Room 5-212,Cambridge,MA,02139**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
The long-term goal of this research is to determine necessary conditions on controllable experimental quantities, such as sample size or signal-to-noise ratio (SNR), so that source localization estimates in a fluctuating ocean waveguide can attain design error thresholds. Using asymptotic expansions of the bias and covariance of maximum likelihood estimates (MLEs) in inverse orders of sample size or SNR,1 we aim to derive an analytical expression for the second-order covariance of MLEs obtained from general complex Gaussian data vectors. This expression can then be used to specify necessary conditions for accurate estimation in many practical problems where both the mean and variance of the measurement are functions of the estimation parameters. Currently such conditions can only be determined in cases where either the mean or the variance of the measurement is parameter dependent, but not both.2 Our ultimate goal is to quantify the effects of internal waves on the biases and variances of source

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

OBJECTIVES

The primary objectives of the research are to:

• Derive an analytical expression for the second-order covariance of MLEs obtained from general complex Gaussian data vectors when both the measurement mean and variance are parameter dependent.

• Determine conditions on sample size and SNR so that source localization estimates attain desired error thresholds in a fluctuating ocean waveguide.

• Quantify the effects of ocean fluctuations on the biases and errors of parameter estimates.

• Derive an analytical expression for the range-velocity ambiguity function of the acoustic field scattered from underwater target groups.

• Develop a method for distinguishing and classifying groups of underwater targets by estimating their second-order velocity and position statistics.

• Publish work already completed on optimally estimating Lambertian surface orientation with application to high frequency sonar imaging.

APPROACH

To determine the conditions necessary to obtain accurate source localization estimates in a fluctuating ocean waveguide, we first expand the bias and covariance of MLEs in inverse orders of sample size or SNR, where the first-order term in the covariance expansion is the Cramer-Rao lower bound (CRLB).[1] We then derive an analytical expression for the second-order covariance of MLEs obtained from general complex Gaussian data vectors. Necessary conditions on sample size and SNR are determined by requiring that the MLEs of source range and depth (i) become asymptotically unbiased and have a variance that attains the CRLB, and (ii) have a CRLB that is within the desired error thresholds. The first condition is achieved when the first-order bias and the second-order covariance are smaller than the true value of the parameter and the first-order covariance, respectively.[1] To model the waveguide containing the random internal waves we employ an already available physical model that provides expressions for the mean, mutual intensity, and spatial covariance of the acoustic field forward propagated through random 3-D internal waves in a stratified ocean waveguide for a continuous wave narrowband signal.[3]

To estimate the instantaneous velocity and position statistics of underwater target groups, we derive analytical expression for the magnitude squared of the range-velocity ambiguity function in terms of the targets' velocity and position statistical distributions. This expression is based on an analytical model for the acoustic field scattered from a simple harmonic source by a single moving target in a stratified waveguide.[4] We then show that the moments of the ambiguity function along constant range and velocity axes are linearly related to the group's first- and second-order statistics in velocity and position, respectively.

WORK COMPLETED

The research work in Fiscal Year 2008 was a great success in developing an analytical expression for the second-order covariance of MLEs based on general complex Gaussian data vectors where both the data mean and variance are parameter dependent. This expression was then used to calculate necessary conditions on sample size and SNR for accurate source localization estimation in a fluctuating ocean waveguide. We also quantified the effects of ocean variability by calculating and comparing the biases and errors of MLEs of source position both in a static waveguide and in the presence of internal waves. We investigated the advantages of using the derived second-order covariance expression by repeating the above calculations for the special cases where either the covariance or the mean of the measurement are assumed to be parameter independent.

Also in Fiscal Year 2008, we derived an analytical expression for the ambiguity function of the acoustic field scattered from groups of underwater targets. This expression was then used to calculate the moments of the ambiguity function magnitude squared along constant range and velocity axes, which were in turn shown to be linearly related to the group's velocity and position statistics, given appropriate signal design. Our approach fully accounts for waveguide dispersion and has been developed with a remote long-range platform in mind, so that simultaneous estimation of range and velocity over continental shelf-scales may be possible. Numerical simulations were employed to model typical cases of migrating and/or randomly swarming fish schools imaged remotely from ranges larger than 10 km.

RESULTS

We developed an analytical expression for the second-order covariance of MLEs obtained from general complex Gaussian data vectors. We used this expression to calculate the conditions necessary to obtain source localization estimates of the desired accuracy and found that sample sizes and SNRs may increase prohibitively by several orders of magnitude when internal wave fluctuations lead to a dominant incoherent intensity component in the total acoustic field intensity. We also investigated the effect of assuming that the measurement corresponded to (i) a deterministic signal vector, or (ii) a fully randomized, zero-mean signal vector, both embedded in additive white noise. We found that in the first case the CRLB, as well as the sample size or SNR necessary to attain it are significantly underestimated, while in the second case they are significantly overestimated.

We developed a method for estimating the statistics of the velocity and position of groups of self-propelled underwater targets using Ocean Acoustics Waveguide Remote Sensing (OAWRS) Doppler analysis. We demonstrated the method using illustrative examples for simulated shoaling and migrating fish shoals, as well as for a group of AUV's. We found that the method performs very well in a typical continental shelf environment and that it is often possible to obtain very accurate (i.e. less than 10% error) estimates of the velocity and position statistics for a single target, as well as for a group of targets. We also found that, typically, a larger number of targets leads to more reliable estimates. Finally, we showed that the second-order statistics can provide a means for target discrimination and classification.

IMPACT/APPLICATIONS

1. Passive Source Localization in a Fluctuating Ocean Waveguide

The calculated biases and errors may be used to quantify the effects of environmental uncertainties on passive source localization techniques, such as matched-field processing (MFP). The results and methodology presented can also be used in experimental design to ensure that statistical biases and errors meet any required thresholds. Further, this research motivates the need for developing analytical models that provide analytical expressions for the statistics of the acoustic field propagating through random and/or fluctuating environments.

2. Velocity Estimation of Underwater Target Swarms

It was recently shown that densely populated fish schools may be the dominant cause of environmental clutter in continental shelf environments.[5] Since the behavioral dynamics of biological scatterers can be expected to differ from those of man-made targets, it is worth examining whether they can be inferred and then used as a means of clutter identification. Instantaneous estimates of the second-order statistics of both the velocity and position of large groups of underwater targets may then provide new opportunities for cutter mitigation.

PUBLICATIONS

• Ioannis Bertsatos, Michele Zanolin, Purnima Ratilal, Tianrun Chen and Nicholas C. Makris, General second-order covariance of Gaussian MLE applied to passive source localization in a fluctuating ocean waveguide, in preparation for submission to J. Acoust. Soc. Am.

• Ioannis Bertsatos, Nicholas C. Makris, Velocity estimation of moving target swarms in a stratified ocean waveguide, in prepartion for submission to J. Acoust. Soc. Am.

• Ioannis Bertsatos, Nicholas C. Makris, Statistical biases and errors inherent in photoclinometric surface slope estimation with natural lights, submitted for publication in Icarus.

• S. Jagannathan et al., Ocean Waveguide Acoustic Remote Sensing (OAWRS) of Marine Ecosystems, accepted for publication in MEPS special issue on Ocean Acoustics.

• Nicholas C. Makris et al., Critical population density triggers rapid formation of vast oceanic fish shoals, Science 323, 1734-1737 (2009).

• Nicholas C. Makris, Purnima Ratilal, Michele Zanolin and Ioannis Bertsatos, Obtaining optimal time-delay, source localization and tracking estimates in free space and in an ocean waveguide, J. Acoust. Soc. Am. 116, 2606 (2004).

• Nicholas C. Makris, Yisan Lai, Ioannis Bertsatos, Deanelle Symonds, Sunwoong Lee and Purnima Ratilal, Expected Doppler shift and spread in long range scattering from fish schools on the continental shelf, J. Acoust. Soc. Am. 116, 2488 (2004).

• Purnima Ratilal, Ioannis Bertsatos, Tianrun Chen, Michele Zanolin and Nicholas C. Makris, Optimal passive source localization in a fluctuating ocean waveguide based on an analytic model for the mean field and covariance, J. Acoust. Soc. Am. 115, 2473 (2004).

• Ioannis Bertsatos and Nicholas C. Makris, Optimally resolving Lambertian surface orientation, J. Acoust. Soc. Am. 114, 2345 (2003).

REFERENCES

[1] Eran Naftali and Nicholas C. Makris, Necessary conditions for a maximum likelihood estimate to become asymptotically unbiased and attain the Cramer-Rao lower bound. Part I. General approach with an application to time delay and Doppler shift estimation, J. Acoust. Soc. Am. 110, 1917-1930 (2001).

[2] Aaron Thode et al., Necessary conditions for a maximum likelihood estimate to become asymptotically unbiased and attain the Cramer-Rao lower bound. Part II. Range and depth localization of a source source in an ocean waveguide, J. Acoust. Soc. Am. 112, 1890-1910 (2002).

[3] Tianrun Chen, Purnima Ratilal and Nicholas C. Makris, Mean and variance of the forward field propagated through three-dimensional random internal waves in a continental-shelf waveguide, J. Acoust. Soc. Am. 118, 3560-3574 (2005).

[4] Yisan Lai and Nicholas C. Makris, Spectral and modal formulation for the Doppler-shifted field scattered by an object moving in a stratified medium, J. Acoust. Soc. Am. 113, 223-244 (2003).

[5] Purnima Ratilal et al., Long range acoustic imaging of the continental shelf environment: The Acoustic Clutter Reconnaissance Experiment 2001, J. Acoust. Soc. Am. 117, 1977-1998 (2005).